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Universe light and the star −**formation history of the The submillimetre extragalactic background**

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L. L. Cowie and A. J. Barger

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The submillimetre extragalactic The submillimetre extragalactic
background light and the star-formation
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history of the Universe history of the Universe
BY L. L. COWIE AND A. J. BARGER

Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA

The submillimetre extragalactic background light is comparable with or exceeds that The submillimetre extragalactic background light is comparable with or exceeds that
of the optical and ultraviolet (UV) wavelength ranges, showing directly that much
of the energy radiated by star formation and active gala The submillimetre extragalactic background light is comparable with or exceeds that
of the optical and ultraviolet (UV) wavelength ranges, showing directly that much
of the energy radiated by star formation and active gala of the energy radiated by star formation and active galactic nuclei is moved to far-
infrared wavelengths. However, it is only as this background at $850 \mu m$ has been of the energy radiated by star formation and active galactic nuclei is moved to far-
infrared wavelengths. However, it is only as this background at $850 \mu m$ has been
resolved with direct submillimetre imaging that we hav infrared wavelengths. However, it is only as this background at 850 μ m has been
resolved with direct submillimetre imaging that we have seen that it is largely cre-
ated by a population of ultraluminous (or near-ultral resolved with direct submillimetre imaging that we have seen that it is largely created by a population of ultraluminous (or near-ultraluminous) infrared galaxies, which appear to lie at relatively high redshifts $(z > 1)$. ated by a population of ultraluminous (or near-ultraluminous) infrared galaxies,
which appear to lie at relatively high redshifts $(z > 1)$. Mapping the redshift evolu-
tion of this major portion of universal star formation which appear to lie at relatively high redshifts $(z > 1)$. Mapping the redshift evolution of this major portion of universal star formation has been difficult because of the poor submillimetre spatial resolution, but this tion of this major portion of universal star formation has been difficult because of the
poor submillimetre spatial resolution, but this difficulty can be overcome by using
extremely deep centimetre continuum radio observa poor submillimetre spatial resolution, but this difficulty can be overcome by using
extremely deep centimetre continuum radio observations to obtain precise astromet-
ric information, since the bulk of the brighter submill extremely deep centimetre continuum radio observations to obtain precise astromet-
ric information, since the bulk of the brighter submillimetre sources have detectable
radio counterparts. With this precise position inform ric information, since the bulk of the brighter submillimetre sources have detectable radio counterparts. With this precise position information available, we find that most of the submillimetre sources are extremely fain radio counterparts. With this precise position information available, we find that
most of the submillimetre sources are extremely faint in the optical and near-infrared
 $(I \gg 24$ and $K = 21{\text -}22)$ and inaccessible to opt most of the submillimetre sources are extremely faint in the optical and near-infrared $(I \gg 24$ and $K = 21-22)$ and inaccessible to optical spectroscopy. Rough photometric redshift estimates can be made from combined radi $(I \gg 24$ and $K = 21-22$) and inaccessible to optical spectroscopy. Rough photometric redshift estimates can be made from combined radio and submillimetre energy distributions. We shall refer to this procedure as millimetr ric redshift estimates can be made from combined radio and submillimetre energy
distributions. We shall refer to this procedure as millimetric redshift estimation to
distinguish it from photometric estimators in the optic estimates can be made from combined radio and subminimetric chorses
distributions. We shall refer to this procedure as millimetric redshift estimation to
distinguish it from photometric estimators in the optical and neardistinguish it from photometric estimators in the optical and near-infrared. These estimators place the bulk of the submillimetre population at $z = 1-3$, where it corresponds to the high-redshift tail of the faint centimetre radio population. While still preliminary, the results suggest that the submill responds to the high-redshift tail of the faint centimetre radio population. While still preliminary, the results suggest that the submillimetre population appears to dominate the star formation in this redshift range by still preliminary, the results suggest that the submillimetre population appears to

Keywords: subm illimetre imaging; redshift evolution; extragalactic background light

1. Introduction

1. Introduction
The cosmic far-infrared (FIR) and submillimetre (SMM) background, which is the
cumulative rest-frame FIR emission from all objects lying beyond our Galaxy has The cosmic far-infrared (FIR) and submillimetre (SMM) background, which is the
cumulative rest-frame FIR emission from all objects lying beyond our Galaxy, has
recently been detected by the FIRAS and DIRBE experiments on t The cosmic far-infrared (FIR) and submillimetre (SMM) background, which is the cumulative rest-frame FIR emission from all objects lying beyond our Galaxy, has recently been detected by the FIRAS and DIRBE experiments on (eumulative rest-frame FIR emission from all objects lying beyond our Galaxy, has recently been detected by the FIRAS and DIRBE experiments on the COBE satellite (Puget *et al.* 1996; Guiderdoni *et al.* 1997; Schlegel *et* \overline{S} recently been detected by the FIRAS and DIRBE experiments on the COBE satellite (Puget *et al.* 1996; Guiderdoni *et al.* 1997; Schlegel *et al.* 1998; Fixsen *et al.* 1998; Hauser *et al.* 1998) and has been found to be comparable with the total unobscured emission at optical/UV wavelengths.[†] This emission at optical/UV wavelengths. This result directly shows that much of the

mic Background Explorer.

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mJy
Figure 1. The 850 µm source counts from Barger *et al.* (1999*a-c*) (filled circles) with 1σ error
limits (iagged solid lines) are well described by the power-law parametrization in equation (2.1) Figure 1. The 850 µm source counts from Barger *et al.* (1999*a–c*) (filled circles) with 1σ error limits (jagged solid lines) are well described by the power-law parametrization in equation (2.1) with $a = 0.4-1.0$, $\$ Figure 1. The 850 µm source counts from Barger *et al.* (1999*a-c*) (filled circles) with 1σ error limits (jagged solid lines) are well described by the power-law parametrization in equation (2.1) with $a = 0.4{\text -}1.0$, limits (jagged solid lines) are well described by the power-law parametrization in equation (2.1)
with $a = 0.4-1.0$, $\alpha = 3.2$ and $N_0 = 3.0 \times 10^4$ deg⁻² mJy⁻¹ (solid line). The dashed curve shows
a smooth extrapolat with $a = 0.4{\text{-}}1.0$, $\alpha = 3.2$ and $N_0 = 3.0 \times 10^4 \text{ deg}^{-2} \text{ mJy}^{-1}$ (solid line). The dashed curve shows
a smooth extrapolation of this fit to match the EBL measurements using the value $a = 0.5$.
Counts from Blain *et* a smooth extrapolation of this fit to match the EBL measurements using the value $a = 0.5$.
Counts from Blain *et al.* (1999) (open circles), Hughes *et al.* (1998) (open triangles), and Eales *et al.* (1999) (open squares

et al. (1999) (open squares) are in good agreement with our data and the empirical fit.
energy released by the totality of star formation and active galactic nuclei (AGN)
radiation through the lifetime of the Universe has energy released by the totality of star formation and active galactic nuclei (AGN)
radiation through the lifetime of the Universe has been dust absorbed and reradiated
into the rest-frame FIR. This in turn, implies that to radiation through the lifetime of the Universe has been dust absorbed and reradiated into the rest-frame FIR. This, in turn, implies that to obtain a full accounting of the radiation through the lifetime of the Universe has been dust absorbed and reradiated
into the rest-frame FIR. This, in turn, implies that to obtain a full accounting of the
history of universal star formation, we must turn into the rest-fra
history of unive
the Universe.

2. Resolving the SMM background

2. Resolving the SMM background
The first stage in this process is to locate the individual objects that give rise to
the background. Resolution of the extragalactic SMM background at 850 um became The first stage in this process is to locate the individual objects that give rise to
the background. Resolution of the extragalactic SMM background at 850 µm became
possible almost simultaneously with the measurement of t The first stage in this process is to locate the individual objects that give rise to the background. Resolution of the extragalactic SMM background at $850 \mu m$ became possible almost simultaneously with the measurement o the background. Resolution of the extragalactic SMM background at 850 μ m became possible almost simultaneously with the measurement of the background when the Submillimetre Common User Bolometer Array (SCUBA; see Hollan possible almost simultaneously with the measurement of the background when the Submillimetre Common User Bolometer Array (SCUBA; see Holland *et al.* 1999) was installed on the 15 m James Clerk Maxwell Telescope (JCMT) on Submillimetre Common User Bolometer Array (SCUBA; see Holland *et al.* 1999)
was installed on the 15 m James Clerk Maxwell Telescope (JCMT) on Mauna Kea.
The SCUBA's sensitivity and area coverage enabled the sources produc was installed on the 15 m James Clerk Maxwell Telescope (JCMT) on Mauna Kea.
The SCUBA's sensitivity and area coverage enabled the sources producing the SMM
background to be directly imaged for the first time. The current The SCUBA's sensitivity and area coverage enabled the sources producing the SMM
background to be directly imaged for the first time. The current count determinations
determined from blank-field surveys and from cluster-len Barger *et al*. 1998, 1999b; Hughes *et al*. 1998; Blain *et al*. 1999; Eales *et al*. 1999) determined from blank-field surveys and from cluster-lensed fields (Smail *et al.* 1997; Barger *et al.* 1998, 1999*b*; Hughes *et al.* 1998; Blain *et al.* 1999; Eales *et al.* 1999) are shown in figure 1. Barger *et al.* Barger *et al.* 1998, 1999*b*; Hughes *et al.* 1998; Blain *et al.* 1999; Eales *et al.* 1999) are shown in figure 1. Barger *et al.* (1999*a-c*) have shown, using optimal fitting techniques combined with Monte Carlo simu are shown in figure 1. Barger *et al.* (1999 $a-c$) have shown, using optimal fitting
techniques combined with Monte Carlo simulations of the completeness of the count
determinations, that the cumulative counts are well fit techniques combined with Monte Carlo simulations of the completeness of the count determinations, that the cumulative counts are well fitted by a power law above determinations, that the cumulative counts are well fitted by a power law above 2 mJy. In addition, they showed that, in order to match the background and fit to the very limited information at fainter magnitudes from the 2 mJy. In addition, they showed that, in order to match the background and fit to the very limited information at fainter magnitudes from the lensed sample (Blain *et al.* 1999), a differential source count law required that
count law
 $n(S) = N_0/(a + S^{3.2}),$

$$
n(S) = N_0/(a + S^{3.2}),\tag{2.1}
$$

 $n(S) = N_0/(a + S^{3.2}),$ (2.1)
was reasonable. Here, S is the flux in mJy, $N_0 = 3.0 \times 10^4 \text{ deg}^{-2} \text{ mJy}^{-1}$, and $a = 0.4$ –1.0 is chosen to match the 850 um extragalactic background light (EBL). The was reasonable. Here, S is the flux in mJy, $N_0 = 3.0 \times 10^4 \text{ deg}^{-2} \text{ mJy}^{-1}$, and $a = 0.4$ -1.0 is chosen to match the 850 μ m extragalactic background light (EBL). The 0.4–1.0 is chosen to match the $850 \mu m$ extragalactic background light (EBL). The *Phil. Trans. R. Soc. Lond.* A (2000)

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comes from $N_0 = 3.0 \times 10^4 \text{ deg}^{-2} \text{ mJy}^{-1}$, and $a = 0.4{\text{-}}1.0$ is chosen to match the 850 μ m EBL. The 95% confidence range for the power-law index is from 2.6 to 3.9.
The extrapolation suggests that the typical SM 850 μ m EBL. The 95% confidence range for the power-law index is from 2.6 to 3.9.
The extrapolation suggests that the typical SMM source producing the bulk of the
background lies at around 1 mJy, and the direct counts s The extrapolation suggests that the typical SMM source producing the bulk of the background lies at around 1 mJy, and the direct counts show that $ca.30\%$ of the 850 μ m background comes from sources above 2 mJy.

Provided only that the redshifts lie near or above $z = 1$ (see below), the FIR 850 μ m background comes from sources above 2 mJy.
Provided only that the redshifts lie near or above $z = 1$ (see below), the FIR
luminosity is approximately independent of the redshift. Thus, if we assume an
ARP 220-li Provided only that the redshifts lie near or above $z = 1$ (see below), the FIR
luminosity is approximately independent of the redshift. Thus, if we assume an
ARP 220-like spectrum with $T = 47$ K (see, for example, Barger luminosity is approximately independent of the redshift. Thus, if we assume are ARP 220-like spectrum with $T = 47$ K (see, for example, Barger *et al.* 1998), the FIR luminosity of a characteristic *ca*. 1 mJy source is i FIR luminosity of a characteristic ca. 1 mJy source is in the range $4-5 \times 10^{11} h_{65}^{-2} L_{\odot}$ ARP 220-like spectrum with $T = 47$ K (see, for example, Barger *et al.* 1998), the
FIR luminosity of a characteristic *ca*. 1 mJy source is in the range $4-5 \times 10^{11} h_{65}^{-2} L_{\odot}$
for a $q_0 = 0.5$ cosmology $(7-15 \times 10^{$ FIR luminosity of a characteristic ca. 1 mJy source is in the range $4-5 \times 10^{11} h_{65}^{-2} L_{\odot}$
for a $q_0 = 0.5$ cosmology (7-15 × 10¹¹ for $q_0 = 0.02$). The FIR luminosity provides a
measure of the current star-format for a $q_0 = 0.5$ cosmology (7–15 × 10¹¹ for $q_0 = 0.02$). The FIR luminosity provides a measure of the current star-formation rate (SFR) of massive stars (Scoville & Young 1983; Thronson & Telesco 1986), SFR $\sim 1.5 \times 1$ measure of the current star-formation rate (SFR) of massive stars (Scoville & Young 1983; Thronson & Telesco 1986), SFR $\sim 1.5 \times 10^{-10} (L_{\rm FIR}/L_{\odot}) M_{\odot} \text{ yr}^{-1}$; a 1 mJy source would, therefore, have an SFR of *ca*. 7 $_{65}^{-2} M_{\odot} \rm ~yr^{-1}$ fo 1983; Thronson & Telesco 1986), SFR $\sim 1.5 \times 10^{-10} (L_{\rm FIR}/L_{\odot}) M_{\odot} \text{ yr}^{-1}$; a 1 mJy
source would, therefore, have an SFR of ca. $70 h_{65}^{-2} M_{\odot} \text{ yr}^{-1}$ for $q_0 = 0.5$, placing the
'typical' SMM source at or above source would, therefore, have an SFR of $ca. 70h_{65}^{-2}M_{\odot}$ yr^{-1} for $q_0 = 0.5$, placing the 'typical' SMM source at or above the high end of extinction-corrected SFRs in optically selected galaxies (Pettini *et al.* 'typical' SMM source at or above the high end of extinction-corrected SFRs in optically selected galaxies (Pettini *et al.* 1998). If we were to allow the dust temperature to go as low as 30 K, $L_{\rm FIR}$ and the correspond to go as low as 30 K , L_{FIR} and the corresponding SFR would be approximately four

3. Direct attempts at a redshift distribution

3. Direct attempts at a redshift distribution
The identification of the optical/near-IR counterparts to the SCUBA sources is made
difficult by the uncertainty in the 850 um SCUBA positions and by the intrinsic faint-The identification of the optical/near-IR counterparts to the SCUBA sources is made
difficult by the uncertainty in the 850 μ m SCUBA positions and by the intrinsic faint-
ness of the counterparts. Barger *et al.* (1999 The identification of the optical/near-IR counterparts to the SCUBA sources is made
difficult by the uncertainty in the $850 \mu m$ SCUBA positions and by the intrinsic faint-
ness of the counterparts. Barger *et al.* (1999 difficult by the uncertainty in the 850 μ m SCUBA positions and by the intrinsic faint-
ness of the counterparts. Barger *et al.* (1999*c*) presented a spectroscopic survey of
possible optical counterparts to a flux-lim ness of the counterparts. Barger *et al.* (1999*c*) presented a spectroscopic survey of possible optical counterparts to a flux-limited sample of galaxies selected from the 850 μ m survey of massive lensing clusters by S possible optical counterparts to a flux-limited sample of galaxies selected from the $850 \mu m$ survey of massive lensing clusters by Smail *et al.* (1997, 1998). The advantage of a lensed survey is that the clusters magnif 850 μ m survey of massive lensing clusters by Smail *et al.* (1997, 1998). The advantage of a lensed survey is that the clusters magnify any background sources, thereby providing otherwise unachievable sensitivity in de tage of a lensed survey is that the clusters magnify any background sources, thereby
providing otherwise unachievable sensitivity in detecting SMM sources, and easing
spectroscopic follow-up in the optical. In the Barger providing otherwise unachievable sensitivity in detecting SMM sources, and easing
spectroscopic follow-up in the optical. In the Barger *et al.* (1999*c*) survey, identifi-
cations were attempted for all objects in the SC spectroscopic follow-up in the optical. In the Barger *et al.* (1999*c*) survey, identifications were attempted for all objects in the SCUBA error boxes that were bright enough for reliable spectroscopy; redshifts or limi cations were attempted for all objects in the SCUBA error boxes that were bright
enough for reliable spectroscopy; redshifts or limits were obtained for 24 possible
counterparts to a complete sample of 16 SCUBA sources: Th enough for reliable spectroscopy; redshifts or limits were obtained for 24 possible
counterparts to a complete sample of 16 SCUBA sources. The redshift survey pro-
duced reliable identifications for six of the SMM sources counterparts to a complete sample of 16 SCUBA sources. The redshift survey produced reliable identifications for six of the SMM sources: two high-redshift galaxy pairs ($a z = 2.8$ AGN/starburst pair (Ivison *et al.* 1998) duced reliable identifications for six of the SMM sources: two high-redshift galaxy pairs ($a z = 2.8$ AGN/starburst pair (Ivison *et al.* 1998) and $a z = 2.6$ Lyman-break-
like pair (Ivison *et al.* 2000); two galaxies show pairs (a $z = 2.8$ AGN/starburst pair (Ivison *et al.* 1998) and a $z = 2.6$ Lyman-break-
like pair (Ivison *et al.* 2000); two galaxies showing AGN signatures ($z = 1.16$ and $z = 1.06$); and two cD galaxies (cluster contami like pair (Ivison *et al.* 2000); two galaxies showing AGN signatures $(z = 1.16$ and $z = 1.06$); and two cD galaxies (cluster contamination). The galaxy pairs were later confirmed as the true counterparts through the detec $z = 1.06$); and two cD galaxies (cluster contamination). The galaxy pairs were later confirmed as the true counterparts through the detection at their redshifts of CO emission at millimetre wavelengths (Frayer *et al.* 19 confirmed as the true counterparts through the detection at their redshifts of CO emission at millimetre wavelengths (Frayer *et al.* 1998, 1999). Because AGN are very uncommon in optically selected spectroscopic samples, emission at millimetre wavelengths (Frayer *et al.* 1998, 1999). Because AGN are very uncommon in optically selected spectroscopic samples, it is also probable that the AGN identifications are correct, and they place a rou uncommon in optically selected spectroscopic samples, it is also probable that the AGN identifications are correct, and they place a rough lower limit of $ca. 20\%$ on the fraction of the SMM sources that have AGN characte AGN identifications are correct, and they place a rough lower limit of $ca. 20\%$ on the fraction of the SMM sources that have AGN characteristics. These results suggest that, excluding the cluster objects, about one-quart fraction of the SMM sources that have AGN characteristics. These results suggest that, excluding the cluster objects, about one-quarter of the SMM sources can be spectroscopically identified.
However, two of the SMM sourc that, excluding the cluster objects, about one-quarter of the SMM sources can be

26, spectroscopically identified.

26, and, while the remaining eight sources have optical galaxies within the large error

26, and, while the remaining eight sources have optical galaxies within the large error

circles However, two of the SMM sources in the sample have no counterparts to I around 26, and, while the remaining eight sources have optical galaxies within the large error circles, these are rather normal objects that may si *Phil. Trans. R. Soc. Lond.* A (2000)

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Figure 2. Radio sources in the HFF: the figure shows an overlay of the 20 cm radio sources in Figure 2. Radio sources in the HFF: the figure shows an overlay of the 20 cm radio sources in
a small region of the HFF on a SCUBA 850 µm image on the right, and on a near-IR image of
the region on the left. (North is to t Figure 2. Radio sources in the HFF: the figure shows an overlay of the 20 cm radio sources in
a small region of the HFF on a SCUBA 850 µm image on the right, and on a near-IR image of
the region on the left. (North is to t the region on the left. (North is to the right and east is to the top in these images.) In general, it is the radio sources that are faint in the optical and near-IR that are detected in the SMM.

it is the radio sources that are faint in the optical and near-IR that are detected in the SMM.

shall show in the next section that this is very probably the case. These missing

sources may be at higher redshifts, or be shall show in the next section that this is very probably the case. These missing sources may be at higher redshifts, or be more dust obscured, than the spectroscop-
ically identifiable sources. Furthermore, Smail *et al.* shall show in the next section that this is very probably the case. These missing
sources may be at higher redshifts, or be more dust obscured, than the spectroscop-
ically identifiable sources. Furthermore, Smail *et al.* sources may be at higher redshifts, or be more dust obscured, than the spectroscopically identifiable sources. Furthermore, Smail *et al.* (1999), using deep near-IR and optical imaging of the fields, recently detected tw ically identifiable sources. Furthermore, Smail *et al.* (1999), using deep near-IR and optical imaging of the fields, recently detected two extremely red objects that may be the counterparts of two of these sources, rath optical imaging of the fields, recently detected two extremely red objects that may be
the counterparts of two of these sources, rather than the nearby bright spiral galaxies
which Barger *et al.* (1999*c*) observed as the the counterparts of two of these sources, rather than the nearby bright spiral galaxies which Barger *et al.* (1999*c*) observed as the most likely counterparts to the SMM sources. This result also suggests that many of t which Barger
sources. This
be suspect.

4. Positional determination from centimetre continuum mination from centin
radio observations

radio observations
To proceed further we need accurate astrometric positions, and these are most easily obtained using centimetre radio continuum observations. Because of the well-known To proceed further we need accurate astrometric positions, and these are most easily
obtained using centimetre radio continuum observations. Because of the well-known
radio–FIR correlation, both the centimetre data and the obtained using centimetre radio continuum observations. Because of the well-known
radio–FIR correlation, both the centimetre data and the SMM observations are lin-
early dependent on the SFRs in the galaxy (Condon 1992), t radio–FIR correlation, both the centimetre data and the SMM observations are linearly dependent on the SFRs in the galaxy (Condon 1992), though the ratio of the $850 \mu m$ flux to the centimetre radio flux rises rapidly as early dependent on the SFRs in the galaxy (Condon 1992), though the ratio of the $850 \mu m$ flux to the centimetre radio flux rises rapidly as a function of redshift because of the opposite signs of the K-correction in the 850 μ m flux to the centimetre radio flux rises rapidly as a function of redshift because
of the opposite signs of the *K*-correction in the two wavelength ranges. (We discuss
this further in the next section.) Because % of the opposite signs of the *K*-correction in the two wavelength ranges. (We discuss this further in the next section.) Because of the redshift dependence, a centimetre flux-limited sample will contain a high proportio this further in the next section.) Because of the redshift dependence, a centimetre flux-limited sample will contain a high proportion of lower redshift objects, while the 850 μ m sample will pick out primarily the high- \bullet flux-limited sample will contain a high proportion of lower redshift objects, while the

 $850 \mu m$ sample will pick out primarily the high-redshift objects.
The flanking field region of the Hubble deep field (the Hubble flanking field (HFF)) is well suited to looking at the radio versus SMM selection. Richards The flanking field region of the Hubble deep field (the Hubble flanking field (HFF))
is well suited to looking at the radio versus SMM selection. Richards (1999) recently
obtained an extremely deep Very Large Aarray 20 cm is well suited to looking at the radio versus SMM selection. Richards (1999) recently
obtained an extremely deep Very Large Aarray 20 cm image of this region, with a
relatively uniform $(1\sigma = 8 \,\mu\text{Jy})$ sensitivity over obtained an extremely deep Very Large Aarray 20 cm image of this region, with a relatively uniform $(1\sigma = 8 \,\mu\text{Jy})$ sensitivity over the whole flanking field region, which can be combined with the deep ground-based opti *Phil. Trans. R. Soc. Lond.* A (2000)

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The *submillimetre extragalactic background light*
the HFF (Barger *et al.* 1999*a*). Richards *et al.* (1999) found that roughly two-thirds
of the 5*σ*-selected 20 cm population have relatively bright optical/NIR counterp the HFF (Barger *et al.* 1999*a*). Richards *et al.* (1999) found that roughly two-thirds of the 5 σ -selected 20 cm population have relatively bright optical/NIR counterparts, while the remaining third are very faint. B

the HFF (Barger *et al.* 1999*a*). Richards *et al.* (1999) found that roughly two-thirds of the 5 σ -selected 20 cm population have relatively bright optical/NIR counterparts, while the remaining third are very faint. B of the 5 σ -selected 20 cm population have relatively bright optical/NIR counterparts,
while the remaining third are very faint. Barger *et al.* (1999 a -*c*) observed a complete
subsample of the radio-selected objects w while the remaining third are very faint. Barger *et al.* (1999 $a-c$) observed a complete subsample of the radio-selected objects with the Low Resolution Imager and Spectrograph on the Keck II 10 m telescope, and found tha subsample of the radio-selected objects with the Low Resolution Imager and Spectrograph on the Keck II 10 m telescope, and found that nearly all the objects with $K < 20$ could be spectroscopically identified, with a maxim trograph on the Keck II 10 m telescope, and found that nearly all the objects with $K < 20$ could be spectroscopically identified, with a maximum redshift of around 1.2; however, almost none of the fainter objects were ide

From a total sample of 70 radio-selected galaxies in the HFF region, Barger *et al.* (2000) chose the 16 with $K > 21$ for follow-up with the SCUBA. However, because they used the jiggle map mode, which provides a *ca*. 5 (2000) chose the 16 with $K > 21$ for follow-up with the SCUBA. However, because they used the jiggle map mode, which provides a *ca*. 5 arcmin² field around the target, (2000) chose the 16 with $K > 21$ for follow-up with the SCUBA. However, because
they used the jiggle map mode, which provides a ca. 5 arcmin² field around the target,
a large fraction of the remaining radio sources (35/ they used the jiggle map mode, which provides a ca. 5 arcmin² field around the target,
a large fraction of the remaining radio sources $(35/54)$ were also serendipitously
measured. Fourteen of the 16 targeted blank-fiel a large fraction of the remaining radio sources $(35/54)$ were also serendipitously measured. Fourteen of the 16 targeted blank-field sources were observed. Even with relatively shallow SCUBA observations $(3\sigma = 6 \text{ mJy at }$ measured. Fourteen of the 16 targeted blank-field sources were observed. Even with
relatively shallow SCUBA observations $(3\sigma = 6 \text{ mJy at } 850 \text{ }\mu\text{m})$, a very large fraction
of the blank-field radio sources were detecte relatively shallow SCUBA observations $(3\sigma = 6 \text{ mJy at } 850 \text{ }\mu\text{m})$, a very large fraction
of the blank-field radio sources were detected in the SMM, as is illustrated in figure 2.
Of the 14 targeted sources, five are d of the blank-field radio sources were detected in the SMM, as is illustrated in figure 2.
Of the 14 targeted sources, five are detected above 6 mJy, while, in contrast, none of
the 35 optical/NIR bright sources were detec the 35 optical/NIR bright sources were detected. In the observed fields, which covered the 35 optical/NIR bright sources were detected. In the observed fields, which covered
slightly more than half of the HFF, a further two sources brighter than 6 mJy were
discovered that were not in the radio sample. Even i slightly more than half of the HFF, a further two sources brighter than 6 mJy were
discovered that were not in the radio sample. Even if there are further non-radio-
detected SMM sources at the same level in the remaining discovered that were not in the radio sample. Even if there are further non-radio-
detected SMM sources at the same level in the remaining unobserved portions of
the HFF, it appears that the radio selection is turning up t ŏ detected SMM sources at the same level in the remaining unobserved portions of the HFF, it appears that the radio selection is turning up the majority of the bright SMM sources.
SMM sources.
The fact that many of the brigh the HFF, it appears that the radio selection is turning up the majority of the bright

SMM sources.
The fact that many of the bright SMM sources can be identified with the opti-
cal/NIR faint radio sources in this way has the extremely important corollary that
many of the 850 um selected sources have extreme The fact that many of the bright SMM sources can be identified with the optical/NIR faint radio sources in this way has the extremely important corollary that many of the 850 μ m selected sources have extremely faint op cal/NIR faint radio sources in this way has the extremely important corollary that
many of the 850 μ m selected sources have extremely faint optical/NIR counterparts.
This is illustrated in figure 3, where we show the K many of the 850 μ m selected sources have extremely faint optical/NIR counterparts.
This is illustrated in figure 3, where we show the K and I magnitudes of radio-selected sources in the HFF, and also in the SSA13 f This is illustrated in figure 3, where we show the K and I magnitudes of radio-
selected sources in the HFF, and also in the SSA13 field (see Richards *et al.* (1999)
and references cited therein), where a similar SMM sur selected sources in the HFF, and also in the SSA13 field (see Richards *et al.* (1999) and references cited therein), where a similar SMM survey has been carried out (Cowie *et al.* 2000). Extremely deep K observations wit and references cited therein), where a similar SMM survey has been carried out (Cowie *et al.* 2000). Extremely deep K observations with the near-IR camera on the Keck I 10 m can yield detections of nearly all the 850 μ Cowie *et al.* 2000). Extremely deep *K* observations with the near-IR camera on the

Keck I 10 m can yield detections of nearly all the 850 μ m detected radio sources, and
 Result these are found to lie in the $K = 21$ Keck I 10 m can yield detections of nearly all the 850 μ m detected radio sources, and these are found to lie in the $K = 21-22$ range. However, many of the sources are not detected in the I band at the 2σ limit of I these are found to lie in the $K=21-22$ range. However, many of the sources are not

The brightest sources lie in the $I = 24{\text -}25$ range.

5. Millimetric redshift estimation

5. Millimetric redshift estimation
While it is clear from the work described in $\S 3$ that a fraction of the SMM sources
have optical and NIR counternarts that are bright enough for spectroscopic identifi-While it is clear from the work described in $\S 3$ that a fraction of the SMM sources
have optical and NIR counterparts that are bright enough for spectroscopic identifi-
cation the results of $\S 4$ show that a very large While it is clear from the work described in $\S 3$ that a fraction of the SMM sources
have optical and NIR counterparts that are bright enough for spectroscopic identifi-
cation, the results of $\S 4$ show that a very larg have optical and NIR counterparts that are bright enough for spectroscopic identification, the results of $\S 4$ show that a very large fraction simply cannot be identified in this way. At the current time, the small numbe cation, the results of $\S 4$ show that a very large fraction simply cannot be identified in
this way. At the current time, the small numbers of objects suggest that perhaps one-
quarter of the sources (of which a fairly l this way. At the current time, the small numbers of objects suggest that perhaps one-
quarter of the sources (of which a fairly large fraction have AGN characteristics) are
bright in the optical and spectroscopically ident quarter of the sources (of which a fairly large fraction have AGN characteristics) are
bright in the optical and spectroscopically identifiable category, while the remainder
fall into the optical/NIR faint category. For th \bullet bright in the optical and spectroscopically identifiable category, while the remainder fall into the optical/NIR faint category. For this latter category of objects, we will have to rely on photometric estimates using the shape of the spectral energy distribution between radio and SMM wavelengths, and the S have to rely on photometric estimates using the shape of the spectral energy distribution between radio and SMM wavelengths, and the SMM to NIR ratios (Carilli & Yun 1999; Blain *et al.* 1999).
Carilli & Yun (1999) have su bution between radio and SMM wavelengths, and the SMM to NIR ratios (Carilli $\&$

as a redshift indicator. Because of the opposing spectral slopes of the synchrotron

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Figure 3. The optical and NIR magnitudes of the radio sources in the HFF and the SSA13 field versus 8.4 GHz flux: the whole radio population is shown as crosses with sources that only have 20 cm fluxes extranolated to 8.4 field versus 8.4 GHz flux: the whole radio population is shown as crosses with sources that only have 20 cm fluxes extrapolated to 8.4 GHz assuming a synchrotron spectrum. Sources with field versus 8.4 GHz flux: the whole radio population is shown as crosses with sources that
only have 20 cm fluxes extrapolated to 8.4 GHz assuming a synchrotron spectrum. Sources with
known redshifts are shown with open only have 20 cm fluxes extrapolated to 8.4 GHz assuming a synchrotron spectrum. Sources with
known redshifts are shown with open diamonds and all lie at $z < 1.2$, except for two quasars
in the SSA13 field (Windhorst *et a* in the SSA13 field (Windhorst *et al.* 1995), which are shown as triangles. Sources that have been observed at 850 μ m, but not detected at the typical 6 mJy (3 σ) level, are shown as small squares, while those detected at 850 μ m are shown as large squares.

squares, while those detected at 850 µm are shown as large squares.
spectrum in the radio and the black-body spectrum in the SMM, the SMM-to-radio
ratio rises extremely rapidly with redshift, as is shown in figure 4 (which spectrum in the radio and the black-body spectrum in the SMM, the SMM-to-radio
ratio rises extremely rapidly with redshift, as is shown in figure 4 (which is taken from
Barger *et al.* (1999*a-c*) in which a much more ext spectrum in the radio and the black-body spectrum in the SMM, the SMM-to-radio
ratio rises extremely rapidly with redshift, as is shown in figure 4 (which is taken from
Barger *et al.* (1999*a*-*c*) in which a much more ex ratio rises extremely rapidly with redshift, as is shown in figure 4 (which is taken from Barger *et al.* (1999 $a-c$) in which a much more extensive discussion may be found). The primary uncertainty in this quantity lies i Barger *et al.* (1999 $a-c$) in which a much more extensive discussion may be found).
The primary uncertainty in this quantity lies in the dust temperature dependence, which, in the local ultraluminous IR galaxy (ULIG) samp The primary uncertainty in this quantity lies in the dust temperature dependinch, in the local ultraluminous IR galaxy (ULIG) sample, produces a range ratio of approximately a multiplicative factor of two relative to ARP 2 ich, in the local ultraluminous IR galaxy (ULIG) sample, produces a range in the
tio of approximately a multiplicative factor of two relative to ARP 220.
We can test the estimator in a variety of ways. In figure 4 we have

ratio of approximately a multiplicative factor of two relative to ARP 220.
We can test the estimator in a variety of ways. In figure 4 we have shown the
average SMM-to-radio ratios for the objects in the HFF with known spe We can test the estimator in a variety of ways. In figure 4 we have shown the average SMM-to-radio ratios for the objects in the HFF with known spectroscopic redshifts. While none of these sources is individually detected, average SMM-to-radio ratios for the objects in the HFF with known spectroscopic
redshifts. While none of these sources is individually detected, the average values
are consistent with a null result at low redshifts and a redshifts. While none of these sources is individually detected, the average values are consistent with a null result at low redshifts and a strongly significant positive detection for the sources near $z = 1$, which is ex are consistent with a null result at low redshifts and a strongly significant positive
detection for the sources near $z = 1$, which is extremely consistent with the ARP 220
ratio. Individual SMM sources with spectroscopic detection for the sources near $z = 1$, which is extremely consistent with the ARP 220 ratio. Individual SMM sources with spectroscopic identifications are also broadly consistent with the expected ratios, though there is ratio. Individual SMM sources with spectroscopic identifications are also broadly consistent with the expected ratios, though there is a suggestion that, as might be expected, those with the AGN characteristics have slight consistent with the expected ratios, though there is a suggestion that, as might be expected, those with the AGN characteristics have slightly lower ratios, though still within the broad general range.

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The submillimetreextragalacticbackground light ²¹³⁹

redshift
Figure 4. Millimetric redshift estimation: the solid curve shows the ratio of the 850 µm to 20 cm
flux that a non-evolving ARP 220 would have as a function of redshift. The solid bar at low Figure 4. Millimetric redshift estimation: the solid curve shows the ratio of the 850 µm to 20 cm
flux that a non-evolving ARP 220 would have as a function of redshift. The solid bar at low
redshift shows the range of the Figure 4. Millimetric redshift estimation: the solid curve shows the ratio of the 850 µm to 20 cm
flux that a non-evolving ARP 220 would have as a function of redshift. The solid bar at low
redshift shows the range of the flux that a non-evolving ARP 220 would have as a function of redshift. The solid bar at low
redshift shows the range of the 850 µm fluxes to the 8.4 GHz flux at low redshift extrapolated
to 20 cm, assuming a synchrotron sp redshift shows the range of the 850 μ m fluxes to the 8.4 GHz flux at low redshift extrapolated
to 20 cm, assuming a synchrotron spectrum with the data taken from Rigopoulou *et al.* (1996).
This suggests that the ULIGs to 20 cm, assuming a synchrotron spectrum with the data taken from Rigopoulou *et al.* (1996).
This suggests that the ULIGs have a range of about a multiplicative factor of two relative to
ARP 220, which is shown by the d ARP 220, which is shown by the dashed lines. The average SMM to 20 cm ratio of the galaxies that have spectroscopic redshifts and have also been observed in the SMM are shown as the large diamonds with 1σ errors. The lowest point is consistent with a null detection, but, in the higher redshift bin, there is a that have spectroscopic redshifts and have also been observed in the SMM are shown as the large diamonds with 1σ errors. The lowest point is consistent with a null detection, but, in the higher redshift bin, there is a large diamonds with 1σ errors. The lowest point is consistent with a null detection, but, in
the higher redshift bin, there is a strong positive detection consistent with an ARP 220 ratio.
Individually detected objects Individually detected objects from Lilly *et al.* (1999) and Ivison *et al.* (2000) are also consistent within the error spread, although those with AGN characteristics (open symbols) appear to fall low in the figure. The within the error spread, although those with AGN characteristics (open symbols) appear to fall for the optically/NIR faint galaxies that are detected in the SMM. Radio objects that are not low in the figure. The solid line shows the best guess for the redshift range (typically $z = 1-3$) for the optically/NIR faint galaxies that are detected in the SMM. Radio objects that are not detected in the SMM are like for the optically/NIR faint galaxies that are detected in the SMM
detected in the SMM are likely to lie at lower redshifts than this,
that are not seen in the radio are potentially at higher redshift.

that are not seen in the radio are potentially at higher redshift.
The radio sources in the HFF, which are faint in the optical and NIR and which have some SMM detections are shown as the horizontal lines in the figure. The The radio sources in the HFF, which are faint in the optical and NIR and which
have some SMM detections are shown as the horizontal lines in the figure. The
redshift estimator places them in the same broad, general, $z = 1$ have some SMM detections are shown as the horizontal lines in the figure. The redshift estimator places them in the same broad, general, $z = 1-3$, range as the typical spectroscopically identified sources. (For AGN, we ma redshift estimator places them in the same broad, general, $z = 1-3$, range as the typical spectroscopically identified sources. (For AGN, we may be systematically underestimating the redshifts). Radio sources without 850 typical spectroscopically identified sources. (For AGN, we may be systematically underestimating the redshifts). Radio sources without 850 μ m detections probably lie at lower redshifts, while the 850 μ m sources with underestimating the redshift
at lower redshifts, while the
the high-end redshift tail.

6. Conclusion

6. Conclusion
We can summarize the results as follows. Approximately 30% of the 850 μ m back-
ground is already resolved and the slope of the counts is sufficiently steep (a power-We can summarize the results as follows. Approximately 30% of the 850 μ m back-
ground is already resolved and the slope of the counts is sufficiently steep (a power-
law index of -2.2 for the cumulative counts) that We can summarize the results as follows. Approximately 30% of the $850 \mu m$ background is already resolved and the slope of the counts is sufficiently steep (a power-
law index of -2.2 for the cumulative counts) that ground is already resolved and the slope of the counts is sufficiently steep (a power-
law index of -2.2 for the cumulative counts) that only a small extrapolation to
fainter fluxes will result in convergence to the bac law index of -2.2 for the cumulative counts) that only a small extrapolation to fainter fluxes will result in convergence to the background. Thus, the typical SMM source contributing to the background seems to be in the fainter fluxes will result in convergence to the background. Thus, the typical SMM
source contributing to the background seems to be in the $1-2$ mJy range. Because of
the direct correspondence between flux and luminosity source contributing to the background seems to be in the $1-2$ mJy range. Because of the direct correspondence between flux and luminosity at these wavelengths we may identify the sources with ULIGs or near-ULIGs. About o *Phil. Trans. R. Soc. Lond.* A (2000) *Phil. Trans. R. Soc. Lond.* A (2000)

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have optical counterparts that are bright enough to be spectroscopically identified,
and a large fraction of these show AGN characteristics, though at least one is an have optical counterparts that are bright enough to be spectroscopically identified, and a large fraction of these show AGN characteristics, though at least one is an extremely bright pair of Lyman-break galaxies. However, **MATHEMATICAL,
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SCIENCES have optical counterparts that are bright enough to be spectroscopically identified, and a large fraction of these show AGN characteristics, though at least one is an extremely bright pair of Lyman-break galaxies. However and a large fraction of these show AGN characteristics, though at least one is an extremely bright pair of Lyman-break galaxies. However, many of the remaining sources are extremely faint at optical and NIR wavelengths $(K$ sources are extremely faint at optical and NIR wavelengths $(K = 21-22)$. Redshift estimation for these sources using the SMM-to-radio ratios places the bulk of them in the same, $z = 1-3$, range as the spectroscopically ide sources are extremely faint at optical and NIR wavelengths $(K = 21-22)$
estimation for these sources using the SMM-to-radio ratios places the b
in the same, $z = 1-3$, range as the spectroscopically identified sources.
It i timation for these sources using the SMM-to-radio ratios places the bulk of them
the same, $z = 1-3$, range as the spectroscopically identified sources.
It is interesting to consider where this population fits into the ove

in the same, $z = 1-3$, range as the spectroscopically identified sources.
It is interesting to consider where this population fits into the overall history
of universal star formation. One uncertainty in doing this is the It is interesting to consider where this population fits into the overall history
of universal star formation. One uncertainty in doing this is the question of what
fraction of the SMM light is powered by AGN rather than s of universal star formation. One uncertainty in doing this is the question of what
fraction of the SMM light is powered by AGN rather than star formation. It has long
been debated whether the dust-enshrouded local ULIGs ar fraction of the SMM light is powered by AGN rather than star formation. It has long
been debated whether the dust-enshrouded local ULIGs are powered by massive
bursts of star formation induced by violent galaxy-galaxy col been debated whether the dust-enshrouded local ULIGs are powered by massive
bursts of star formation induced by violent galaxy-galaxy collisions or by AGN
activity. A recent mid-IR spectroscopic survey of 15 ULIGs by Genze bursts of star formation induced by violent galaxy-galaxy collisions or by AGN activity. A recent mid-IR spectroscopic survey of 15 ULIGs by Genzel *et al.* (1998) found that 70-80% of the samples are predominantly powere activity. A recent mid-IR spectroscopic survey of 15 ULIGs by Genzel *et al.* (1998) found that 70-80% of the samples are predominantly powered by star formation and 20-30% by a central AGN. Thus, while the spectroscopic found that 70–80% of the samples are predominantly powered by star formation
and 20–30% by a central AGN. Thus, while the spectroscopic follow-up studies of
the gravitationally lensed SMM sample (Barger *et al.* 1999*c*; and 20–30% by a central AGN. Thus, while the spectroscopic follow-up studies of the gravitationally lensed SMM sample (Barger *et al.* 1999*c*; Ivison *et al.* 1998) discussed in $\S 3$ indicate that at least 20% of the sa the gravitationally lensed SMM sample (Barger *et al.* 1999*c*; Ivison *et al.* 1998) discussed in §3 indicate that at least 20% of the sample show some AGN activity, we shall assume, in the following discussion, that a s discussed in $\S 3$ indicate that at l
we shall assume, in the following dight arises from star formation.
Several groups (Smail *et al.* 19 Several groups (Smail *et al.* 1998; Eales *et al.* 1999; Lilly *et al.* 1999; Trentham *al* 1999. Barger *et al.* 1999*a*-*c*) have suggested that the SMM sources are asso-

et al. 1999; Barger *et al. 1998;* Eales *et al. 1999;* Lilly *et al. 1999;* Trentham *et al. 1999;* Barger *et al. 1999a*-*c*) have suggested that the SMM sources are asso-
ciated with major merger events giving rise to Several groups (Smail *et al.* 1998; Eales *et al.* 1999; Lilly *et al.* 1999; Trentham *et al.* 1999; Barger *et al.* 1999 $a-c$) have suggested that the SMM sources are associated with major merger events giving rise to t *et al.* 1999; Barger *et al.* 1999 $a-c$) have suggested that the SMM sources are associated with major merger events giving rise to the formation of spheroidal galaxies. The approximate equality of the optical and SMM bac ciated with major merger events giving rise to the formation of spheroidal galaxies. The approximate equality of the optical and SMM backgrounds supports this hypothesis; present-day spheroidal and disk populations have ro ies. The approximate equality of the optical and SMM backgrounds supports this
hypothesis; present-day spheroidal and disk populations have roughly comparable
amounts of metal density, and, thus, their formation is expecte hypothesis; present-day spheroidal and disk populations have roughly comparable
amounts of metal density, and, thus, their formation is expected to produce compara-
ble amounts of light (Cowie 1988). Since the volume dens amounts of me
ble amounts of
(*ca*. $10^{-6}h_{65}^3$ M
see for examp f metal density, and, thus, their formation is expected to produce compara-
ts of light (Cowie 1988). Since the volume density of local ULIGs is very low
 ${}^{3}_{65}$ Mpc⁻³ for objects with bolometric luminosities above 5 ble amounts of light (Cowie 1988). Since the volume density of local ULIGs is very low $(ca.10^{-6}h_{65}^{3}$ Mpc⁻³ for objects with bolometric luminosities above $5 \times 10^{11}h_{65}^{-2}L_{\odot}$; see, for example, Sanders & Mirab (*ca.* $10^{-6}h_{65}^3$ Mpc⁻³ for objects with bolometric luminosities above $5 \times 10^{11}h_{65}^{-2}L_{\odot}$;
see, for example, Sanders & Mirabel (1996)), it appears that the SFR in this population must have been much higher i see, for example, Sanders & Mirabel (1996)), it appears that the SFR in this population must have been much higher in the past and must have declined very steeply after $z = 1$, which may also be consistent with this inter **MATHEMATICAL,
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SCIENCES** lation must have been much higher in the past and must have declined very steeply
after $z = 1$, which may also be consistent with this interpretation. For a cumula-
tive source density of $4.0 \times 10^4 \text{ deg}^{-2}$, required to after $z = 1$, which may also be consistent with this interpretation. For a cumulative source density of $4.0 \times 10^4 \text{ deg}^{-2}$, required to reproduce the EBL with 1 mJy sources $\langle N \rangle = \text{EBL}/\langle S \rangle$ with $\langle S \rangle \sim 1 \text{ mJy$ tive source density of $4.0 \times 10^4 \text{ deg}^{-2}$, if
sources $(\langle N \rangle = \text{EBL}/\langle S \rangle \text{ with } \langle S \rangle \sim 1$
average space density is $5 \times 10^{-3} h_{65}^3$ M
 $a_0 = 0.02$) This space density is rather ⁻², required to reproduce the EBL with 1 mJ
 \sim 1 mJy), and redshifts in the 1-3 range, th
 ${}^{3}_{65}$ Mpc⁻³ for a $q_0 = 0.5$ cosmology (10⁻³ for

the insensitive to the upper cut-off on the rec sources $\langle N \rangle = \text{EBL}/\langle S \rangle$ with $\langle S \rangle \sim 1 \text{ mJy}$, and redshifts in the 1-3 range, the average space density is $5 \times 10^{-3} h_{65}^3$ Mpc⁻³ for a $q_0 = 0.5$ cosmology $(10^{-3}$ for $q_0 = 0.02$). This space density is rath average space density is $5 \times 10^{-3} h_{65}^3$ Mpc⁻³ for a $q_0 = 0.5$ cosmology (10^{-3} for $q_0 = 0.02$). This space density is rather insensitive to the upper cut-off on the redshift distribution, dropping by only a fact for $q_0 = 0.02$). This space density is rather insensitive to the upper cut-off on the redshift distribution, dropping by only a factor of around 2 or 3 if we extend the volume calculation to $z = 5$. For comparison, the space ution, dropping by only a factor of around 2 or 3 if we extend the volume
to $z = 5$. For comparison, the space density of present-day ellipticals
 3 ₆₅ Mpc⁻³ (Marzke *et al.* 1994). Within the still-substantial unc shift distribution
calculation to z
is *ca*. $10^{-3}h_{65}^3$ M.
posed by the dual calculation to $z = 5$. For comparison, the space density of present-day ellipticals
is $ca. 10^{-3}h_{65}^3$ Mpc⁻³ (Marzke *et al.* 1994). Within the still-substantial uncertainty
posed by the dust temperatures, the estimat is *ca*. $10^{-3}h_{65}^3$ Mpc⁻³ (Marzke *et al.* 1994). Within the still-substantial uncertainty posed by the dust temperatures, the estimated SFR from SMM sources in the $z = 1-3$ range is *ca*. 0.3h₆₅ M_{\odot} yr⁻¹ Mp range is $ca. 0.3h_{65}M_{\odot}$ yr^{-1} Mpc⁻³ for $q_0 = 0.5$, which is nearly an order of magnitude higher than that observed in the optical range, $ca. 0.04h_{65}M_{\odot}$ yr^{-1} Mpc⁻³ (see, for example, Steidel *et al.* 199 range is $ca. 0.3h_{65}M_{\odot}$ yr⁻¹ Mpc⁻³ for $q_0 = 0.5$, which is nearly an order of magnitude higher than that observed in the optical range, $ca. 0.04h_{65}M_{\odot}$ yr⁻¹ Mpc⁻³ (see, of proposition of the sylid of ex tude higher than that observed in the optical ration example, Steidel *et al.* 1999), suggesting the bulk of the star formation at these redshifts. (see,

bulk of the star formation at these redshifts.
We thank our collaborators Eric Richards, Dave Sanders, Ian Smail, Rob Ivison, Andrew Blain
and Jean-Paul Kneib We thank our collabora
and Jean-Paul Kneib.

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